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WOOD IN WAR AND PEACE

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WOOD IN WAR AND PEACE[1]

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Our present-day reliance upon wood, not as a temporary wartime expedient, but in full recognition of its rightful position as a standard and traditionally important engineering material, affords conspicuous evidence of the striking advances made in wood technology and wood utilization since World War I. The clearly demonstrated ability of a wide variety of wood products to fulfill the exacting requirements of many of their current uses, and the unending search for ways and means of broadening their sphere of usefulness, offer great promise for the extended utilization of wood in the postwar period, even in the face of continued improvements in competitive materials.

The impact of wartime requirements has naturally provided a great stimulus for research in wood utilization and, in fact, has so accelerated such activity that developments which ordinarily would require years to attain are being achieved in a matter of months. However, full recognition should be given to the fact that much of the progress made since the outbreak of the war, while fostered by war demands and war economy, has been due to the foundation of significant discoveries built during the years preceding the conflict. Many of the present-day applications of wood in military construction, in the fabrication of aircraft and naval craft, and in other critical wartime uses had their roots in the knowledge of design data, wood characteristics, adhesives, fabrication techniques, and associated factors acquired during the past 35 years. While there are necessarily many parallels between the wood uses of World Wars I and II, there are also many products being employed in the present conflict, such as modified wood and plastics, which were unknown 25 years ago; other products, such as plywood and laminated wood, have been so improved as to be virtually new.

In more than a few outstanding instances, the revived or intensified interest in wood and the resultant extension of its use have been aided by a critical shortage of other essential materials, particularly metals. This has been true in the use of wood in the construction of aircraft, aircraft hangars, truck bodies, landing barges, and assault vessels. Currently, the greater availability of metal has somewhat alleviated the earlier critical shortage, and there is an increased tendency in some quarters to anticipate an early curtailment in the use of wood in favor of metal for certain

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purposes. This attitude is accentuated by metal-minded engineers and manufacturers, who have regarded the use of wood in some types of contruction as a temporary stopgap, and by the fact that heavy demands have caused wood, in turn, to be regarded as a critical material. Whether or not wood will be able to maintain its current position of importance in what are sometimes considered replacement fields will depend upon the continued development of new wood products and the improvement of old ones in the face of increased competition with metals, plastics, and other materials.

The changing demands for wood occasioned by the shift from peacetime to wartime economy is illustrated in the current requirements for construction and for packaging. The use of wood for civilian construction, of which residential and farm construction, maintenance, and repair are outstanding examples, showed a steady decline from approximately 22-3/4 billion board feet in 1941 to less than 11-1/2 billion board feet in 1943; a further decline is predicted for 1944. At the same time, requirements for military construction and exports, including lend-lease, rose from 5 billion board feet in 1941 to more than 12 billion board feet the following year; then, with the progressive completion of construction of cantonments, warehouses, hangars, shipyards, and other large-scale military projects in this country, consumption of wood for this purpose declined to slightly more than 6-1/2 billion feet in 1943. During 1944, a further decline is anticipated, with an estimated consumption of less than 4 billion feet, although this figure may be revised sharply upward, as more men go overseas and operations expand on the fighting fronts, necessitating an increased exportation of lumber to meet military construction needs in Europe and the Pacific.

The over-all decrease in construction-lumber requirements from 1941 to 1944 has been largely compensated by the mounting demand for the boxes and crates required to keep war equipment and supplies moving in a steadily increasing stream to our armed forces and our allies on the fighting fronts all over the world. The 1941 consumption of lumber for boxes and crates amounted to 5-1/2 billion board feet, or approximately 15 percent of the total lumber consumption for that year, and was used chiefly for the domestic movement of agricultural products and other civilian commodities. By comparison, the 1943 requirements totaled 16-1/2 billion feet, of which 12-1/2 billion feet were used for direct military needs and almost 2 billion feet more for indirect military purposes. It is anticipated that a still greater volume of lumber will be needed to meet packaging requirements during 1944. So great have the current needs for wood boxes and crates become, that lumber for this purpose is now classified as critical, despite the extensive use of fiberboard to supplement the demand for container stock. Great improvements have been made in container design and construction, as well as in interior-packing procedures, to insure the safe transportation of material. Much has also been done in the matter of conserving critical shipping space and, incidentally, container materials, An estimated reduction of 20 percent in cubic displacement through the redesign of export containers, means that, on the average, four ships can now carry the volume of equipment and supplies which formerly required five.

Perhaps the outstanding example of improved wood utilization is shown to be in the aircraft fabrication field when a comparison is made of the "flying crate" of World War I with the Mosquito bomber of today. In contrast

to the situation in this country, where the use of wood in aircraft, while extensive, has been largely restricted to training planes and gliders, the British are reported to have 40 different types of fighter and trainer planes using varying percentages of wood, as well as meeting 60 percent of their propeller requirements with wood. While favored by the shortage of critical metals, the revived use of wood in aircraft construction, following a period during which the wood airplane had come to be regarded in many quarters as practically obsolete, is in very large measure the result of the development of improved glues and plywood and distinct advances in design and fabrication methods.

Further evidence of the adaptability of wood to the rigorous demands of modern warfare is its use in the construction of naval craft. Solid wood, laminated stock, and plywood are basic structural components in a number of ships, including landing vessels, assault craft such as the famous PT boats, patrol boats, subchasers, mine layers, mine sweepers, and auxiliary craft. Wood is a standard item for the decking of steel-hulled battleships and flight decks of aircraft carriers; large quantities of lumber are required for the wooden shipways and scaffolding needed in the construction of such enormous ships. One of the outstanding applications of wood in Navy use is in the construction of hangars for coastal-patrol blimps. Wood has been used extensively in these structures, the largest of which is 1,000 feet long, 170 feet high at the crown, and nearly 300 feet wide at the base.

Wood in the Construction Field

Wood has been prominent in meeting wartime requirements for military and essential civilian construction ranging from relatively conventional structures, such as cantonments, factory buildings, supply depots, and some housing projects for war workers, to forms unique because of size or new applications of wood. In this latter category are such structures as gigantic hangars for housing Navy blimps and mobile dry docks for salvaging or reconditioning warships, as well as certain types of prefabricated building units designed for housing and industrial structures.

Two relatively new developments have been largely responsible for the increased adaptability of wood in the heavy-construction field. The introduction of timber connectors in this country about 1930 and the pioneering use of laminated arches in 1935 were definite milestones in an extension of heavy-timber construction which has been most helpful in this war period and promises much for the continued expansion in the use of wood in the postwar construction.

Timber Connectors

The use of timber connectors was developed as a means of bolstering an inherent weakness in conventional timber construction, namely, the inability of the steel bolts used in joining wood members to develop any large part of the natural strength of the wood. The relatively small cross sections of the bolts cause the loads transmitted from one member to another to be applied as shearing forces on restricted areas of wood. Metal connectors, used in

conjunction with bolts, distribute the stresses over a much greater area of wood, and thus increase the shear resistance between the wood members to insure joints four or five times as strong as those attained with bolts alone. The efficiency of timber connectors is well exemplified in the construction of radio towers. Formerly towers were limited to heights of about 100 feet because of the weakness of the bolted joints; now they can be erected to heights of 300 to 400 feet. Timber connectors in "fireproofed" timber trusses of blimp hangars make possible the construction of clear roof spans as long as 237 feet. The resultant increase in efficiency of wood structural members has extended the application of timber to diverse, and often intricate, types of construction. Today, timber connectors are making possible the extensive use of wood in the construction of railroad and highway bridges, shipways, airplane hangars, factory buildings and warehouses. Worthy of special mention are the prefabricated, connector-built, 160-foot span trusses in permanent bridges built to carry the Alcan highway over some of the Alaskan rivers.

Laminated Construction

Further impetus to the use of wood in construction has been afforded by the development of laminated structural units, made by bonding boards, or relatively small pieces of wood, with suitable water-resistant glues to form straight or curved members. Such members, prefabricated at the factory and assembled on the job, have essentially the same properties as solid wood, but are no longer restricted in size by the dimensions of logs from which solid timbers can be cut, or limited to the conventional shapes and curvatures of such solid units.

Perhaps the chief development in this field is the adaptation of laminated units in the construction of roof arches of varied sizes and shapes designed to afford wide floor areas unimpeded by supporting columns. These arches are curved to follow side walls and roof slopes and designed to conform to the varying concentrations of load. The first building in the United States successfully employing laminated arch construction was erected in 1935; since then such units have been widely used for both utilitarian and architectural purposes in a large variety of structures, to provide clear spans ranging from 25 feet or less to 300 feet or more. Included on the list are gymnasiums, skating rinks, recreation halls, churches, theaters, factories, warehouses, hangars, aircraft assembly plants, and similar buildings, both large and small. The use of laminated arches has also been extended to outside installations, notably for small-bridge construction. The successful use of these structural units was based on extensive prewar research on a wide variety of associated design and construction problems, and on the evolution of the data requisite to the sound engineering application of the principles involved.

A more distinctly wartime application of this type of construction is in the use of laminated ship timbers in the construction of small naval craft. Counterparts of the glued-wood arch are the curved keels and frame members used in building ships, as a replacement for the hewn timbers of large cross section formerly employed. One of the recent developments has been the use of straight laminated timbers for the mud sills and head logs of prefabricated wood invasion barges. The successful application of wood in such naval craft construction was made possible by the development of a new type glue that

is durable in contact with salt water and sets at a temperature sufficiently low to make practical its use in heavy laminating.

In addition to its use in the form of structural timbers, laminated wood has extensive application in the fabrication of automobile and truck bodies, airplane parts (wing beams, struts, and propellers), furniture, gunstocks, shoe lasts, shuttle blocks, and many other items.

House Construction

Studies conducted in recent years have enhanced the competitive position of wood in the housing field by reducing construction and maintenance costs and otherwise increasing the serviceability of frame structures. Of particular significance have been investigations of design factors, including the strength and rigidity of frame walls; determinations of the effectiveness of vapor barriers in overcoming moisture condensation in walls; tests of the fire-resistance of structural units; and research on painting problems.

One of the outstanding achievements, particularly for low-cost housing, has been the development of unit, or prefabricated, construction. Such construction had its inception several years before the war, but was restricted in its more favorable application until the introduction of moisture-resistant plywood. With the onset of the war, the acute need for living accommodations for war workers in crowded communities so stimulated the demand for low-cost housing that thousands of prefabricated plywood structures have been built in the past several years. There is some question about the adequacy of some of this construction, especially that which was specifically intended as a temporary housing expedient. In consequence, there is a possibility that undesirable results involving serious maintenance may give prefabricated housing in general an unwarranted poor reputation and thus tend to hinder its postwar development. It may not be commonly realized that there is a tremendous difference in quality between temporary war housing and prefabricated construction adequately designed, and properly made, for permanent homes.

The fabrication of good quality factory-made plywood housing panels employs the monocoque or stressed skin principle common in aircraft design, each floor, wall, and roof unit comprising a panel of standard unit size having two plywood faces bonded with water-resistant synthetic-resin glue to a solid wood framework. Insulation, moisture barriers, wiring and plumbing can be factory-installed within the space between the plywood faces, and both exterior and interior finish applied in advance by machine methods, thus further simplifying the final construction at the building site.

Plywood

Perhaps the outstanding achievements in wood utilization in recent years have been in the use of plywood. The critical needs of the greatly expanded aircraft and shipbuilding industries resulted in an extensive demand for plywood. This, in turn, served as an incentive to research which has been particularly fruitful in developing new and improved adhesives, revolutionarizing

production methods and equipment, evolving better fabrication techniques, and supplying requisite design data and other essential information. In consequence of these developments, plywood is today meeting the most exacting requirements of warfare, as attested by its use in the construction of the Mosquito bomber, the torpedo-carrying PT boat, and numerous other structures, including refrigerated compartments in some of the new Liberty ships.

Adhesives

The advent of synthetic-resin glues, and their steady improvement during the past few years, have been primarily responsible for bringing plywood to the fore in the war construction program. In the last year or two these adhesives have appeared in increasing number and with varying properties and uses. Essentially, the most outstanding of the resin glues embody water resistance heretofore unattainable, durability, strength, and quick-setting properties. Such glues have wide application, not only for plywood, but also in the production of laminated arches and other forms of glued construction for exterior as well as interior use. They provide bonds fully as strong and durable as the wood itself, and impart increased dimensional stability to the glued structures.

A recent advance in adhesives has been the development of glues for bonding wood to metal and to plastics, an advance which promises to further extend the use of wood. When thin metals are superimposed upon plywood, the resultant product is comparable in certain respects to more expensive thick metal parts.

Molded Plywood

One of the conspicuous developments in plywood is the production of curved shapes, or molded plywood. The use of mating dies for the production of simple curved forms, such as chair backs and drawer fronts, and the steam bending of flat-pressed plywood are not new. But the development of improved synthetic-resin adhesives and of new processes, such as bag molding or fluid-pressure molding, have made possible the rapid and extensive production of parts having pronounced and compound curvatures which could not satisfactorily be attained by other available methods. Such so-called molded plywood has wide application in marine and aircraft uses in the production of half fuselages, small aircraft units, and small boat hulls. Complete airplanes made of molded units have been built and successfully flown. Molded plywood is also being used in the manufacture of structural shapes, such as angles, channels and even I-beams, as well as plywood tubing of practically any length and with inside diameters ranging from a fraction of an inch to 2 feet or more. These tubes have been used for a number of military purposes, such as collapsible tent poles and radio antenna masts up to 90 feet tall. The substitution of molded-plywood tubing for the metal formerly used for radio masts has resulted in a reduction of as much as 90 percent in the weight of these structures.

New Products

Investigations relating to the application of synthetic resins to wood, especially in attempts to control shrinking and swelling and to overcome certain seasoning difficulties, have led to the development of a group of new products, sometimes classified under the broad heading of wood plastics. The basic factor in the development of these products was the discovery that the treatment of wood with synthetic resins or with urea results in a definite modification of the material and improvement of certain of its properties. These changes result from the recognized facts that lignin, the cementing substance which surrounds and binds the cellulose fibers in wood, can be plasticized by chemical treatment and made to flow, and that bonding the added chemical groups to the cellulose of the fiber wall and to the interfiber lignin will alter the physical behavior of the wood.

Resin-impregnated Wood

When wood is impregnated with an unpolymerized synthetic resin of the phenolformaldehyde type which diffuses into the cell-wall structure, and is subsequently heated to cause the resin-forming materials to cure or set, these additives bond chemically to the fibers in the wood. The resultant complex of insoluble resin and wood has a high degree of moisture resistance and, consequently, relative freedom from shrinking and swelling. It also exhibits definite improvement in certain strength properties, notably hardness and compression, as well as increased resistance to acids, decay, and fire, and decreased electrical conductivity. It is, however, adversely affected in one important strength property, namely, toughness. With plywood or laminated wood, the treatment may be applied throughout or only to the exterior or face ply, thus providing a surface which resists weathering and checking when exposed in the exterior construction. The product of this type developed by the Forest Products Laboratory has been named impreg.

Plywood or laminated wood of somewhat different character is produced when the resin-impregnated plies are hot pressed. Since the resin has a plasticizing effect on the lignin, the treated wood may be compressed under moderate pressures at the same time that the resin is set, thus acquiring added density. The extent of densification is dependent upon the force applied in the press; a pressure of 1,000 pounds per square inch will increase the specific gravity of practically any species of wood to 1.3 to 1.4. The resultant product, like the uncompressed resin-impregnated material, is highly resistant to shrinking and swelling, as well as resistant to fire and decay. Furthermore, the densified material is greatly improved in all mechanical properties, except impact strength (toughness), and has a surface hardness of 60 to 90 as compared with that of plate glass at 100. It also has a high-gloss finish which, in effect, permeates the whole structure; surface scratches can be removed merely by sanding and buffing, and cut surfaces can be brought to a high finish by similar treatment. In addition, the natural finish is highly resistant to such organic solvents as alcohol and acetone, which destroy most applied finishes. The material can be molded to various shapes during the compressing-heating treatment; it can also be made with varying density from one part to another. Such material developed at the Forest Products Laboratory is known as compreg.

Combination materials may be formed in a single hot-pressing operation, with resin-treated compressed faces bonded to untreated or resin-treated uncompressed (precured) cores. The uncured faces become plasticized under the action of the heat of the press and consequently may be considerably compressed under relatively low assembly pressures (200-250 pounds per square inch) which cause only a slight compression of the core. The resultant material thus attains greatly improved surface hardness and strength with relatively little increase in weight over uncompressed wood.

Resin-impregnated, compressed material (plywood and laminated wood) is now being used in the production of such aircraft parts as propellers, radio antenna masts, chart cases, and bucket seats; and in the manufacture of bearings, gears, rollers, bearing plates, and similar products.

Laminated Paper-base Plastics

A new development, somewhat comparable to that of resin-impregnated, compressed wood, is the production of a high-tensile-strength plasticlike paper laminate used experimentally as a substitute for light metals in the production of stressed aircraft parts, such as wing ribs, wing-tip skins, and control surfaces. The product is made of thin sheets of special types of paper impregnated with synthetic resin and compressed together to form sheets or molded shapes; its properties may be varied to meet special requirements.

Paper laminates treated with phenolic resins have been used for several years for electrical insulating panels and for other nonstructural uses that do not require high strength properties. The new development provides a plastic with twice the tensile strength of the earlier paper laminates and equal to aluminum in tension, on a weight basis. Available experimental data indicate that it can be molded to desired shapes on equipment now used for making plywood, at similar temperatures and pressures; that it is resistant to moisture and remains stable at both high and low temperatures; that it is more resistant to scratching and denting than aluminum; and that it does not splinter, tear, or flower when pierced by bullets. The characteristic smooth surface of the plastic eliminates the necessity of special finishes and coatings. The product gives promise for use in water craft ranging from small boats to parts of cargo vessels, and in the hulls of flying boats. The Laboratory has named this material papreg.

"Sandwich" Materials

"Sandwich" materials represent a composite construction designed to use certain properties of the combined materials to best advantage. In such construction, low-density woods, pulpboard, or other light filler substances can be surfaced with relatively high density, strong, durable materials, such as plywood or resin-impregnated compressed wood. The outstanding current use of material of this type is in the Mosquito bomber, in which the gluing of plywood faces to a low-density balsa wood core affords a lightweight construction of considerable thickness and of relatively high strength and stiffness. The structural bonding of metal faces to a wood core may also be considered as a form of sandwich construction.

Urea-plasticized Wood

Considerable attention is being devoted to a plasticizing process which was discovered in the course of studies on the use of urea in the chemioal seasoning of wood. When green wood is soaked in a solution of urea, dried at temperatures not exceeding 140° F., and heated to about the boiling point of water, the wood becomes plastic and can be twisted, bent to extreme curvatures, or otherwise shaped. Upon cooling, the wood again becomes rigid and retains its new shape. This same type of plasticization can be applied to sawdust to form solid sheets or panels. The product formed is thermoplastic, however, and is subject to losing its new shape when reheated to 212° F. By this treatment the wood is appreciably darkened.

By adding a resin-forming chemical, such as formaldehyde, to the urea solution and altering the treatment, a thermosetting product can be formed that will retain its shape when reheated. Such a product has moisture resistance that is lacking in the thermoplastic form. It is stiffer and considerably harder than normal wood, takes a high polish when buffed, and is bleached rather than darkened by the treatment. While this product is still in the striotly experimetnal stage, it appears to have possibilities in the postwar development of wood products.

Miscellaneous Developments

No attempt has been made to cover all of the developments in modified wood products, or to discuss wood derivatives and new wood-processing methods, some of which are finding current use while others are still in the experimental stage. Included in the list are heat-stabilized, compressed wood; lignin-bonded wood plastics, in the form of molding powders and laminating sheets; pulp-reinforced plastics; and low-density resin-treated fiberboards. Definite advances are being made also in "fireproofing" wood, chemical seasoning, and electrostatic heating.

Postwar Aspects of Wood Products Utilization

The extent and rapid pace of current progress in wood research tend to cloud the picture of postwar utilization of wood products and, yet, to point to the adaptation to peacetime service of materials and processes developed for war. Wartime experience with wood has brought new recognition of its versatility as an engineering material. Many of the products involved will have been tested in the crucible of unusually exacting war requirements, and accordingly should be capable of meeting the most severe service needs of peacetime consumer goods in various parts of the world.

Indications point to an accelerated utilization of wood in postwar housing, which will presumably have its inception soon after the removal of wartime restrictions on civilian construction. It has been estimated that more than 10 million new homes will be needed in the United States in the first decade after the war. It is expected that both prefabricated structures and conventional housing will be important in meeting the postwar needs. Added

to the accumulated housing demands in this country will be the requirements for rehabilitation in Europe and other war-devastated areas.

Heavy demands are anticipated for structural forms of wood, for use in all types of farm and urban construction and by the transportation, mining, and communication industries, both in this country and abroad. Timber connectors and laminated arches, beams, and other structural elements are expected to find wide application, because of the increasing shortage of high-grade solid wood in requisite sizes.

There is definite expectation that, in many of their applications, as in making aircraft, furniture, and automobiles, the new steels, white metals, plastics, and plywoods will be used in combination rather than as replacements for one another. The satisfactory application of metal-covered plywood and solid wood, made possible by the development of suitable adhesives, opens an extensive potential market and presages many applications and unique uses. These combinations will afford constructions and uses that take advantage of the best qualities and properties of each material for a given purpose. The intelligent use of plywood, plastics, and light metals in conjunction will provide many items definitely superior to those made of one material alone.

The successful adaptation of moisture-resistant plywood to the most exacting aircraft and marine requirements offers every assurance of its extensive postwar use for utilitarian and decorative purposes. The exhaustive studies now being made, under the stress of the acute wartime need for plywood design criteria, are providing data which will be of inestimable value in promoting the structural application of plywood in the construction of buildings, airplanes, boats, and automobiles.

The application of molded plywood appears especially promising, in its potential extended use for house construction, lightweight furniture, aircraft parts, small boats and various naval craft parts, automobile and truck bodies, special piping or tubing, and musical instruments.

The current developments of modified (resin-impregnated) wood, both the densified form and the uncompressed type, should afford extensive outlets for wood in the postwar era. The successful performance of the densified material in war uses indicates its adaptability to consumer needs where outstanding strength, high durability, resistance to wear and marring, and attractive appearance are important. Suggested outlets include table and counter tops, trays, and other household articles for which cigaretteproof, alcoholproof, and waterproof surfaces are an advantage; fine furniture, luggage, and novelties; paneling and other architectural details; ski runners and other sporting goods; ship decking; face plies in the skins of aircraft plywood and in shells of boats, pontoons, and like structures requiring water resistance; and industrial ventilating fans and similar articles which require not only strength and stability, but also resistance to corrosive atmospheres. Full attainment of many of these uses will be dependent upon the ability of the producers of densified wood products to meet the competitive price of other materials; while relatively expensive at present, quantity production of resin-impregnated compressed wood products may be expected to result in appreciably lowered costs.

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The uncompressed resin-impregnated wood will probably find application, especially as production costs are lowered, for items in which relative freedom from shrinking and swelling, and durability are important requisites, such as parts of aircraft, boats, and vehicles, exterior doors, electric cabinets, precision instruments, and sporting goods.

The future use of wood plastics, in competition with plastics from other sources, will be determined by relative costs, serviceability, and general consumer appeal. Their performance in war material and the production experience gained by war contractors who may use these plastics in quantity will have a significant bearing on the postwar application of the wood derivatives.

The application of laminated paper plastics to consumer needs offers much promise, especially when decorative treatments are given to this durable, strong, and dimensionally stable material.

The quantity of wood used for shipping containers is unquestionably destined to be diminished in the postwar era, when improved handling and less adverse shipping and storing conditions and a marked contraction in the export movement of supplies bring a renewed emphasis on relatively low-cost, lightweight fiberboard. Solid wood, veneer, and plywood, however, may still be expected to fill an important need in the rail, truck, and water movement of certain agricultural products and of heavy and fragile consumer goods. They also have possibilities in the design of lightweight, compact containers for air transportation, although the low tare weight and relative cost of improved fiberboards will be a distinct competitive disadvantage for wood. Attention is being devoted to the combination of wood and fiberboard as a means of incorporating the advantages of both materials in shipping containers.

A definite increase in the over-all use of wood is predicted for the years immediately following the war. This may involve an extension of use in housing and general construction, a reduction in aircraft and containers, and the invasion of new fields with improved and novel products.

In the inevitable postwar competition of improved steels, light metals, plastics, ceramics, and glass, the ability of wood and wood products to hold the gains of the past several years will be dependent upon the unabated research efforts of the chemist, engineer, and wood technologist, and upon the aggressive support of the wood industries and associated agencies in exploiting the advanced techniques and pushing the conventional, improved, and new products in both established and new fields of use. Unlike the wartime era, the postwar development of markets for wood products will have to be made without benefit of shortages in competing materials; the utilization of wood products will, of necessity, be on their own merits and must be economically sound.